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(54) APPARATUS AND METHOD FOR ADJUSTING THE COLOR TEMPERATURE OF WHITE SEMICONDUCT OR LIGHT EMITTERS

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Related U.S. Application Data

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(52) U.S. Cl. 315/179; 315/291; 362/285; 362/800
(58) Field of Search 315/178, 179, 315/291, 307, 312, 360, 362; 362/208, 800, 285

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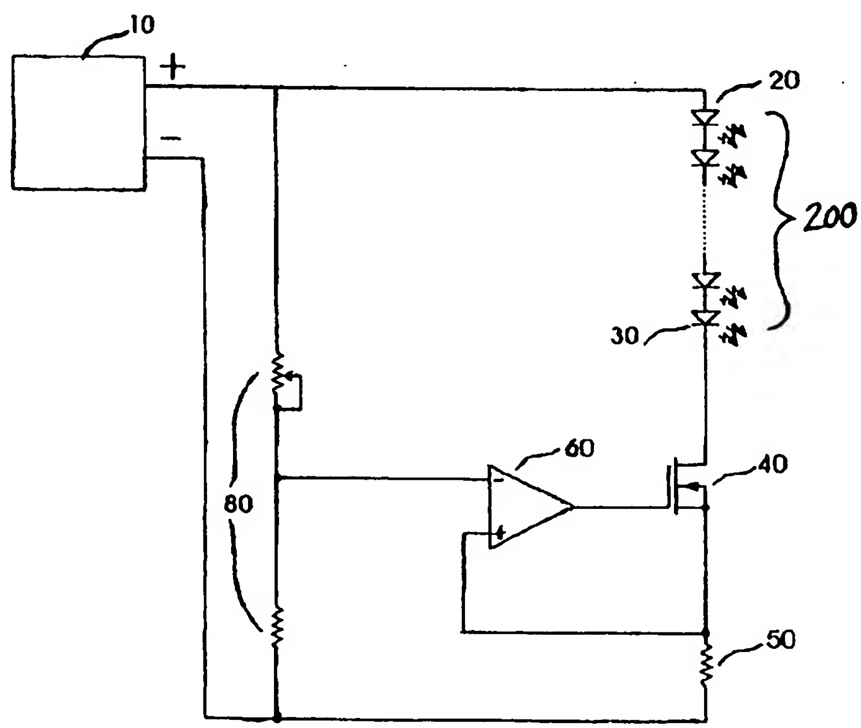
(57) **ABSTRACT**

An LED arrangement which produces a color temperature adjustable white light. The LED arrangement includes one or more white LEDs and a first drive circuit operable to supply a first drive current to the one or more white LEDs such that a white light is output at a desired intensity. The LED arrangement further includes one or more colored LEDs arranged such that a light output from the one or more colored LEDs combines with the white light to produce a resultant light having a desired color temperature. The colored LEDs are driven by a second drive circuit which supplies a second drive current to the one or more colored LEDs such that a colored light is output at a desired intensity, the intensity of the colored light output from the one or more colored LEDs being adjustable so as to adjust the color temperature of the resultant light.

46 Claims, 6 Drawing Sheets



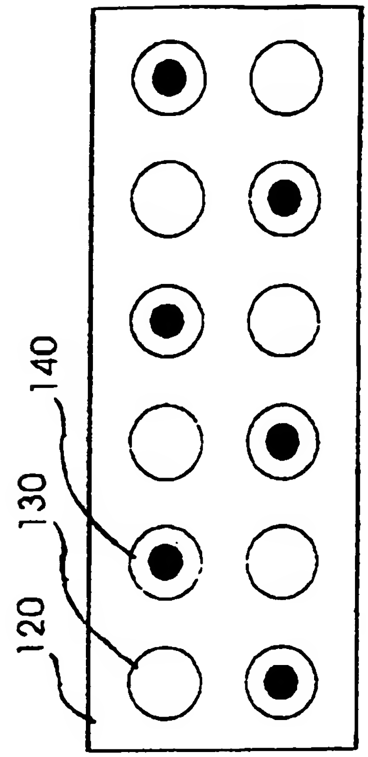


Figure 1B

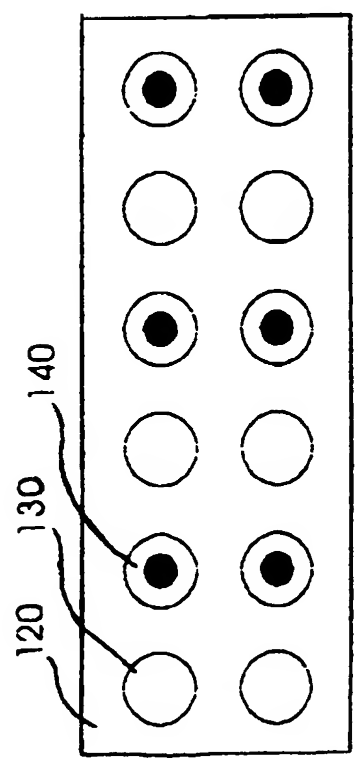


Figure 1A

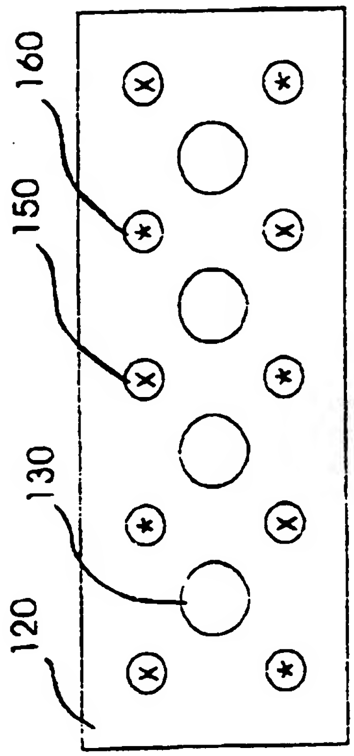


Figure 2B

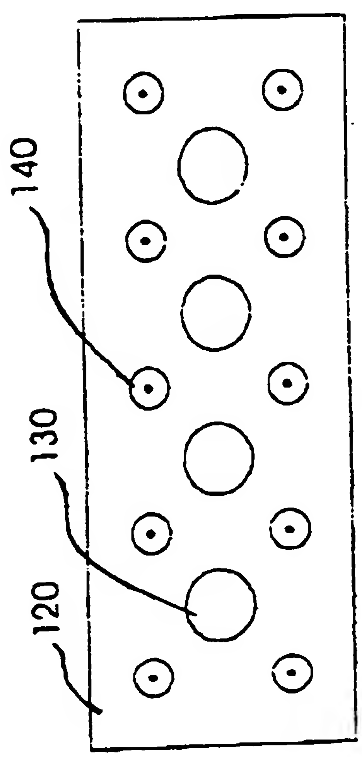


Figure 2A

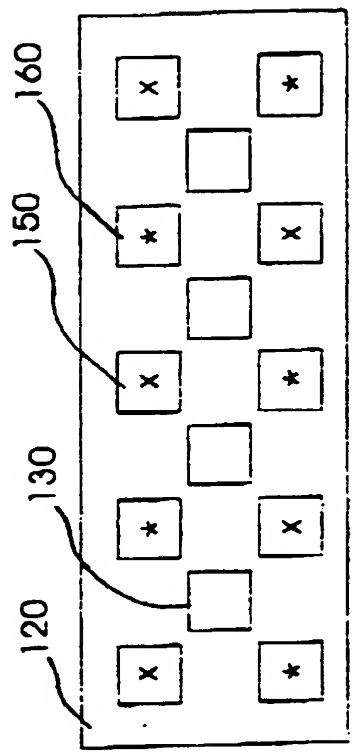


Figure 3B

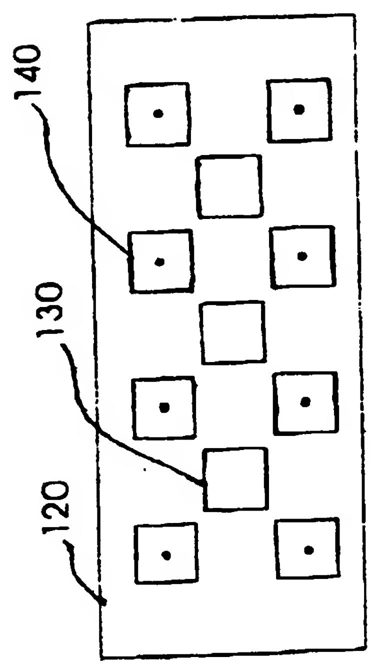


Figure 3A

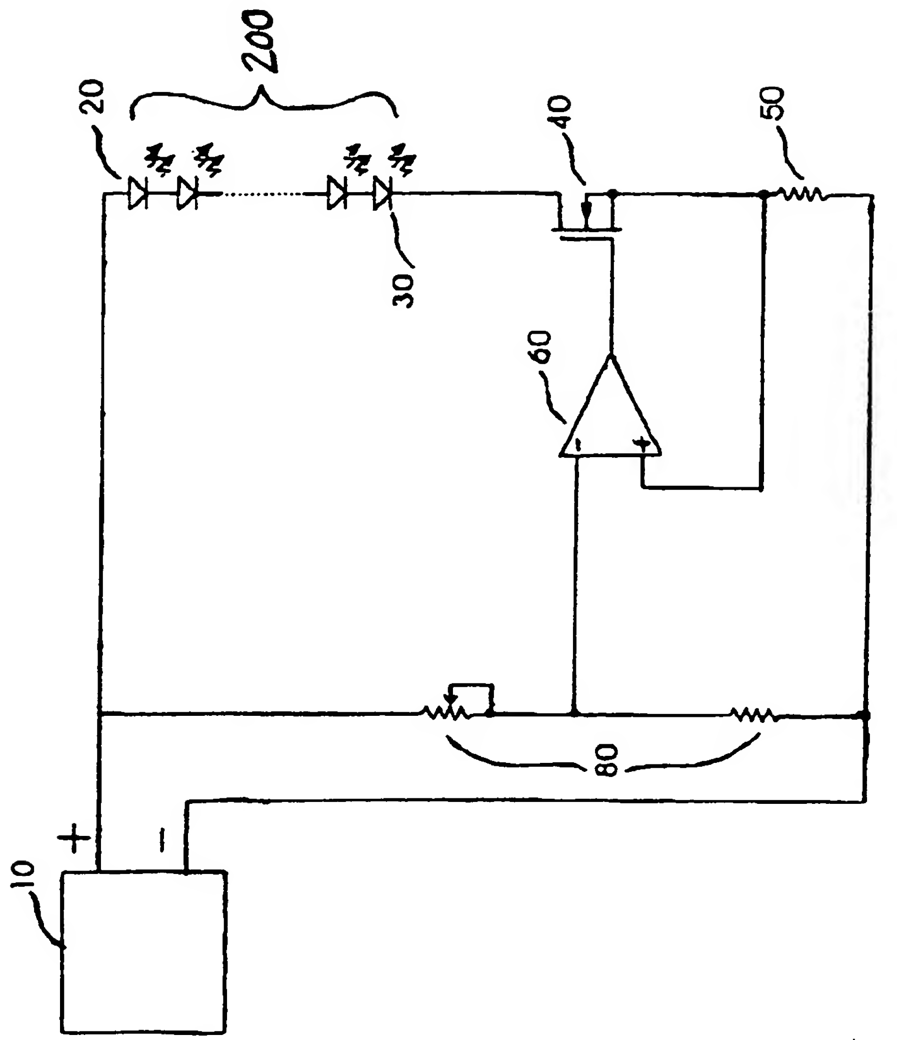


Figure 4

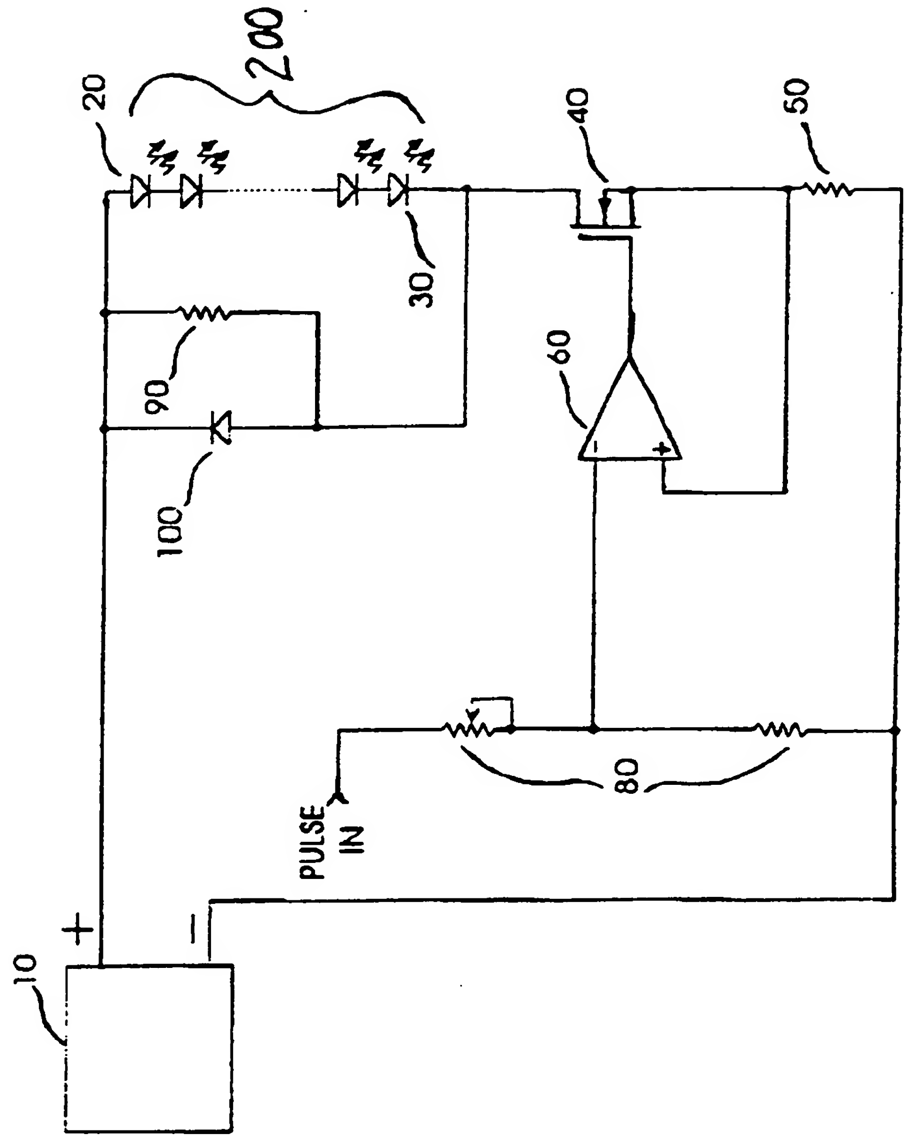


Figure 5

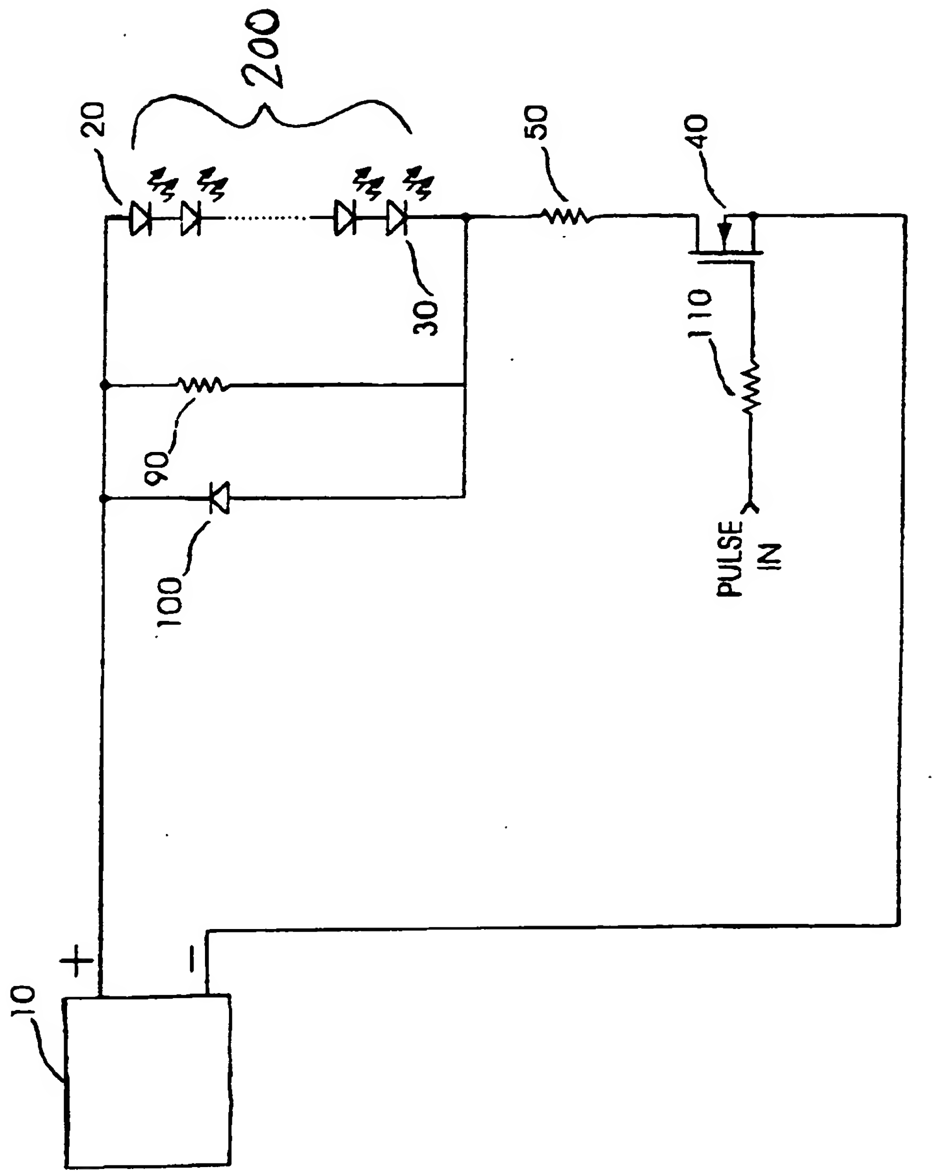


Figure 6

APPARATUS AND METHOD FOR ADJUSTING THE COLOR TEMPERATURE OF WHITE SEMICONDUCT OR LIGHT EMITTERS

CROSS REFERENCE TO RELATED APPLICATION

This application claims the benefit and priority of U.S. Provisional Application Ser. No. 60/230,265 filed Sep. 6, 2000 entitled "A METHOD FOR ADJUSTING THE COLOR TEMPERATURE OF SEMICONDUCTOR LIGHT EMITTERS".

FIELD OF THE INVENTION

The present invention relates to a semiconductor light emitting diode (LED) array. In particular, the present invention relates to a semiconductor LED array which is adjustable by a user for the selection of a desired color temperature. Also, the present invention relates to a method of selecting a desired color temperature from an array of LEDs.

BACKGROUND OF THE INVENTION

The color temperature of light is typically measured in degrees Kelvin (K). This measurement system was first adapted to measure the temperature of stars. With this color temperature scale, the colder the light, the higher the degrees K, i.e., the hotter the star, the bluer the light output. This temperature scale is also used to measure the light output of other light sources, such as incandescent bulbs, fluorescent lamps and LEDs, to name a few.

To provide the proper contrast for items in an individual's viewing environment, it is desirable to have a white light output from a light source. The use of incandescent bulbs and flourescent lamps have effectively provided such a white light or near white light output. However, there are significant drawbacks to the use of these types of light sources for illumination, such as fragility of the lights themselves and their relatively short lifespan. With incandescent bulbs, for example, their output color temperature will shift toward the red end of the spectrum with a drop in line voltage. Also, changes in the output color temperature due to bulb aging are particularly problematic in color photography or cinematography applications where changes in color temperature due to aging over a very short period (i.e., 48 hours of operation) necessitate the frequent changing of very expensive bulbs.

Because of the drawbacks in the use of incandescent and fluorescent lights, the use of LEDs for illumination has become increasingly popular. However, because LEDs use semiconductor principles of operation to produce light, their light output is typically along a narrow wavelength band, i.e., a single color output. Recent advances, however, have resulted in LEDs which produce a near white light output.

Presently, there are two methods utilized to output white light from LEDs. The first method uses triads of red, green, and blue LEDs. This first method requires a very careful balancing of the brightness of each of the three colors to obtain a white light output. Once the white light output is established, an extremely fine adjustment is then required to obtain the desired color temperature. This is because variations within a fraction of a percent in the intensity of any one color LED will result in a perceptible change in the overall output color temperature of the white light. Further, as the light output of the LEDs vary with age, the ambient temperature changes, and the drive current supplied to the LEDs varies even slightly, the color temperature of the white light will exhibit unwanted fluctuations.

One method for dealing with this problem is to adjust the LEDs for as pure a white light output as possible, and then correct for color temperature using tinted filters. This method ameliorates the color shift problem, but results in significant light losses.

The second method for generating white light is to use a special type of LED which produces a white light output. This special LED produces a white light output by coating the emitting surface of a high intensity blue LED with a phosphor which emits yellow light. The yellow light is emitted as a secondary emission as a result of the phosphor being excited by the photons from the blue LED junction. The spectral output of these devices shows a very high output at the wavelengths in the blue end of the spectrum and a moderate spike in the output at the wavelengths near the yellow portion of the spectrum. Thus, the overall output of the device is a white light with a relatively high color temperature. Such high temperature white LEDs are available from Nichia Chemical Corporation. These white LEDs are available over a range of color temperatures from 5000 deg. K to 8500 deg. K. To obtain lower color temperatures so as to approximate the light from an incandescent lamp, i.e., a color temperature of about 3600 deg. K, a color correcting filter with its attendant light losses must be used.

Therefore, there remains a need for a white light LED which is simple and can be easily adjusted to produce a white light of a desired color temperature.

SUMMARY OF THE INVENTION

The present invention provides an LED arrangement which produces a color temperature adjustable white light. The LED arrangement includes one or more white LEDs, a first drive circuit operable to supply a first drive current to the one or more white LEDs such that a white light is output at a desired intensity. The LED arrangement also includes one or more colored LEDs arranged such that a colored light output from the one or more colored LEDs combines with the white light to produce a resultant light having a desired color temperature. A second drive circuit is provided to supply a second drive current to the one or more colored LEDs such that the colored light is output at a desired intensity. The intensity of the colored light output from the one or more colored LEDs is adjustable such that the color temperature of the resultant light is adjustable.

In the preferred embodiments, the colored LEDs are either amber LEDs, or a combination of red and yellow LEDs. The LEDs used can be either discrete LEDs or "chip-on-board" LEDs.

With this arrangement of LEDs and driver circuits, the color temperature of a white LED can be effectively adjusted without the output color temperature being sensitive to aging, fluctuations in ambient temperature and changes in drive current. The ability of the present invention to effectively adjust the color temperature of the resultant light to reduce the effects aging, fluctuations in ambient temperature and changes in drive current is a result of utilizing the additive properties of light, as opposed to using subtractive properties, such as color filters and their attendant light losses.

Further, the LED arrangement of the present invention allows for the adjustment of the color temperature over a wide range and achieves the desired color temperature even when the intensity of the light varies by several percent in either direction without causing a perceptible change in color temperature.

BRIEF DESCRIPTION OF THE DRAWINGS

Other features and advantages of the present invention will become apparent from the following description of embodiments of the invention which refers to the accompanying drawings, wherein:

FIGS. 1A and 1B are plan views of various LED arrangement patterns according to a first embodiment of the present invention;

FIGS. 2A and 2B are plan views of various LED arrangement patterns according to a second embodiment of the present invention; and

FIGS. 3A and 3B are plan views of various LED arrangement patterns according to a third embodiment of the present invention;

FIG. 4 is a schematic diagram of a constant current drive circuit for use with the LED arrangement of the present invention;

FIG. 5 is a schematic diagram of a pulse width modulated current drive circuit, with active current limiting, for use with the LED arrangement of the present invention; and

FIG. 6 is a schematic diagram of a pulse width modulated current drive circuit, with passive current limiting, for use with the LED arrangement of the present invention.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

Referring now to the drawings, FIGS. 1A through 3B show plan views of various LED arrangements according to various embodiments of the present invention. In each of FIGS. 1A through 3B, the LEDs 130, 140, 150, 160 are shown as being mounted to a printed circuit board or other suitable substrate 120. In FIGS. 1A through 3B, circles represent cylindrical, or discrete LEDs and rectangles represent surface mount devices, or chip-on-board devices. White LEDs are indicated by reference numeral 130 and an absence of any mark within the outline. Amber LEDs are indicated by reference numeral 140 and a dot (•) within the outline. Yellow LEDs are indicated by reference numeral 150 and a cross (X) within the outline and red LEDs are indicated by reference numeral 160 and a star (★) within the outline.

The white LEDs 130 are arranged on the substrate 120 so as to be driven by a first drive circuit, such as, for example, one of the circuits shown in FIGS. 4 through 6. The first drive circuit supplies a first drive current to the white LEDs 130 such that a white light is output at a desired intensity. The operation of the drive circuits will be described in greater detail below.

The colored LEDs (i.e., the amber 140, yellow 150 and/or red 160 LEDs) are arranged on the substrate 120 such that a light output from these one or more colored LEDs 140, 150 and/or 160 combines with the white light output from the white LEDs 130 to produce a resultant light having a desired color temperature. A second drive circuit, such, for example, one of the circuits shown in FIGS. 4 through 6, is connected to the colored LEDs 140, 150 and/or 160 so as to supply a second drive current to the colored LEDs 140, 150 and/or 160 such that a colored light is output at a desired intensity. In the embodiments described below, the colored LEDs 140, 150, 160 may be driven by one or more drive circuits such as those shown in FIGS. 4 through 6. For example, if only amber LEDs 140 are used as the colored LEDs, only one drive circuit may be needed. However, if both yellow and red LEDs 150, 160 are used as the colored LEDs, then the yellow and red LEDs 150, 160 may be arranged such that only one drive circuit is needed to supply the drive current thereto, or each of the yellow and red LEDs 150, 160 may be provided with their own independently adjustable drive circuits such that the drive current supplied to the yellow LEDs 150 is independently adjustable relative to the drive current supplied to the red LEDs 160. With either of these colored LED arrangements, the intensity of the colored light output therefrom is adjustable such that the color temperature of the resultant light can be adjusted as desired.

FIG. 1A is a plan view of an array of white LEDs 130 evenly spaced and interleaved with amber 140 LEDs of the same size. The array is repetitive and may be extended indefinitely in either direction. To achieve the desired color temperature, the drive current to the white LEDs 130 is held at a constant level and the drive current to the amber LEDs 140 is adjusted until the desired color temperature is reached. This method effectively balances out the high output spike from the white LEDs 130 in the blue end of the spectrum without requiring the use of colored filter materials. In this embodiment, as in the others whose descriptions follow, the use of the white LEDs 130 with the addition of a warmer color (i.e., amber LEDs 140, or yellow and/or red LEDs 150, 160), results in a simpler and more tolerant adjustment of output white light than that which can be achieved with the red-green-blue LED array of the prior art.

FIG. 1B is a plan view of a staggered array of white LEDs 130 and amber LEDs 140 of the same size. This embodiment is used where a more thorough mixing of the light is required, such as where the light source is closer to the item or target that is to be illuminated.

FIG. 2A is a plan view of another LED arrangement according to an embodiment of the present invention. As shown in FIG. 2A, the LED arrangement includes an array of evenly spaced 5 mm diameter white LEDs 130 wherein each white LED 130 is surrounded by four 3 mm diameter amber LEDs 140. This embodiment is used where the closer spacing afforded by the 3 mm devices permits a more compact design of the overall LED arrangement. The increased number of amber LEDs 140 in this embodiment is dictated by the lower light output of these smaller units.

FIG. 2B is a plan view of a further embodiment of an LED arrangement of the present invention. As shown in FIG. 2B, the LED arrangement includes an array of evenly spaced 5 mm diameter white LEDs 130 wherein each white LED 130 is surrounded by alternating pairs of 3 mm red 160 and yellow 150 LEDs. This embodiment is used where a lower color temperature, i.e., with a greater amount of light in the red portion of the spectrum, is required than is obtainable with the amber LED 140 embodiments. In this embodiment, the drive current to the white LEDs 130 is held constant and the drive currents to the yellow and red LEDs 150, 160 are adjustable together or independently of one another.

FIG. 3A is a plan view of an LED arrangement wherein all the LEDs in the array are surface mount devices and a mixture of white LEDs 130 and amber LEDs 140 are used. FIG. 3B shows an LED arrangement similar to that of FIG. 3A except that yellow LEDs 150 and red LEDs 160 are used in the array in place of the amber LEDs 140. The embodiments shown in FIGS. 3A and 3B are preferred where an extremely low profile lighting device is desired.

The operation of the various LED arrangements of the present invention will now be described in detail while referencing FIGS. 1A through 6. In the circuit diagrams of FIGS. 4 through 6, the LEDs are referred to generally as reference numeral 200. Reference numeral 200 represents either the white LEDs 130 or the colored LEDs 140, 150,

160 as provided within the drive circuit. In other words, reference numeral 200 indicates the location of the white LEDs 130, the amber LEDs 140, or the yellow and/or red LEDs 150, 160 within the drive circuit.

With the present LED arrangement, the white LEDs 130 are provided with a first drive circuit which supplies an adjustable constant drive current thereto, while the colored LEDs (i.e., either the amber LEDs 140, or the yellow and red LEDs 150, 160) are provided with a second drive circuit. The drive circuit for the white LEDs 130 preferably supplies a constant drive current to the white LEDs 130 and is preferably capable of being adjusted such that the intensity (brightness) of the emitted white light can be varied. The colored LEDs 140, 150, 160 are preferably provided with a second drive circuit which supplies a drive current to the colored LEDs 140, 150, 160 which is also adjustable such that the intensity of the output colored light can be varied and thereby provide the proper mix of colored and white light so as to achieve the desired color temperature. Examples of suitable drive circuits and their operation will be described below with reference to FIGS. 4 through 6.

FIG. 4 shows one type of current drive circuit for use with the LED arrangements shown in FIGS. 1A through 3B of the present invention. In particular, FIG. 4 shows an adjustable constant current drive circuit for a string of LEDs 200. In FIG. 4, reference numeral 10 denotes a DC power source. The DC power source 10 provides a positive voltage to the uppermost anode 20 of the one or more LEDs 200. Preferably, the string of LEDs 200 are connected in series. However, when more than one string of LEDs are used, each of the LEDs in the string can be connected in 110 series and then each string can be connected in parallel. Due to the differences in the forward voltage drops of different LEDs, the length of the series strings will be determined by the supply voltage. For example, in a 24 V_{DC} circuit, series strings of five white LEDs 130 would be paralleled and connected to their respective driver, and a series strings of ten yellow or red LEDs 150, 160 would be paralleled and connected to their respective driver.

Returning to FIG. 4, the lowermost cathode 30 in the string of one or more LEDs 200 is preferably connected to the drain of an N channel field effect transistor (FET) 40. The source of the FET 40 is returned to the negative side of the DC power source 10 through resistor 50. The gate of the FET 40 is driven by an operational amplifier 60. The inverting input of the amplifier 60 is connected to the source of the FET 40, and the non-inverting input is connected to a voltage source through variable resistive divider 80.

The operational amplifier 60 provides a voltage proportional to the desired LED current by the voltage divider 80. By varying the voltage from the voltage divider 80, the current is varied. In other words, the voltage from the voltage divider 80 sets the operating current for the string of LEDs 200. The operational amplifier 60 supplies a drive voltage to the gate of the FET 40 causing it to conduct current. When the voltage across the current sense resistor 50 is equal to the voltage provided by voltage divider 80, the amplifier 60 maintains the drive voltage level. By selecting the ratio of the two resistors comprising the voltage divider 80, the desired output current can be selected and will remain constant, independent of changes in the output voltage of the DC source 10 or changes in the forward voltage drop of the LEDs 200. With this drive circuit, the drive current of the LEDs 200 can be adjusted to a desired level and held constant at that level. The nature of this drive circuit is such that it will adjust its drive to maintain the constant drive current. Thus, if the power supply 10 voltage changes or the forward voltage drop across the LEDs 200 changes with time and/or temperature, the operational amplifier 60 will adjust its drive accordingly so as to maintain a constant current.

FIG. 5 shows a second type of current drive circuit for use with the LED arrangement of the present invention. In particular, FIG. 5 shows a pulse width modulated drive circuit with active current limiting. The circuit of FIG. 5 is basically the same as that of FIG. 4, except that the non-inverting input of the operational amplifier 60 is driven by positive-going pulses through a resistive voltage divider 80. In other words, the voltage being used to determine the current is pulsed rather that being provided at a DC level. In this configuration, an additional resistor 90 and a diode 100 are connected in parallel with the series string of LEDs 200.

The drive circuit of FIG. 5 permits the adjustment of the current supplied to the LEDs 200, and thus the intensity of the light emitted by the LEDs 200. This circuit permits adjustment by varying the duty cycle of a pulse stream driving the operational amplifier 60. In this circuit, the drive to the FET 40 is established when the voltage across the sense resistor 50 is equal to the amplitude of the input pulse. In this embodiment, the brightness of the LEDs 200 are determined by the average current through the LEDs 200. For example, if the pulse is such that the FET 40 is conducting 50% of the time, the average current will be 12 the peak current. This type of brightness control is particularly suitable when a microprocessor is used as a programmable control element to adjust the light output of the LEDs 200.

When the operational amplifier 60 is operating from a single, positive supply voltage, its output can be a slightly positive voltage even though the pulse input voltage is zero volts during the "off" portion of the duty cycle. This slight positive voltage causes FET 40 to conduct sufficient current to permit the LEDs 200 to emit a small amount of light. At a low current, the voltage drop across resistor 90 is much smaller than the forward voltage drop across the LEDs 200. For this reason, the LEDs 200 will be back-biased in this condition and will turn off completely.

Because the operational amplifier 60 and the FET 40 are high speed devices, inductive spikes may be introduced at the leading and trailing edges of the drive pulse. The more distant the LEDs 200 are from the driver, and thus the longer the connecting wires, the greater the spikes become in amplitude. The addition of the diode 100 clamps the output of the drive circuit to the supply voltage 10 to protect the LEDs 200 and the FET 40. The generation of the inductive spike may be reduced by slowing down the switching speed of FET 40. This may be accomplished, for example, by placing a capacitor from the gate of the FET 40 to ground (not shown). This may, however, result in undesirable switching losses.

FIG. 6 shows a third type of current drive circuit for use with the LED arrangement of the present invention. In particular, FIG. 6 shows a pulse width modulated drive circuit with passive current limiting. The circuit of FIG. 6 is similar to that of FIG. 5, except that the operational amplifier is omitted and FET 40 is driven directly by the positive-going pulses through a resistor 110. Accordingly, there is no feedback in the circuit to maintain a constant current. This circuit is useful in applications where some current variation is allowable and cost is a primary consideration. In this embodiment, the variation in current will be due primarily to changes in the supply voltage. Accordingly, if the LEDs 200 are operated from a well-regulated power supply 10, the current variations will be minor.

In the drive circuit of FIG. 6, resistor 50 acts as a passive current limiter. This drive circuit can be used where the regulation of the LED current against changes in input voltage, forward voltage drop, etc., is not critical enough to justify more complex circuitry. Resistor 90 and diode 100 are incorporated to prevent small leakage currents that may keep the LEDs 200 from conducting and to protect against inductive spikes. Resistor 110 protects the FET 40 from being overdriven.

With the above arrangement of drive circuits and LED components, the light from one or more white LEDs can be adjusted to a color temperature between from about 2500–5000 degrees Kelvin. In a preferred embodiment, the color temperature of the white light is set to about 3600 degrees Kelvin. Additionally, because of the means used to achieve the lower color temperature described above, the intensity of the light can vary by several percent without causing a perceptible change in color temperature.

Further, the above arrangement of drive circuits and LED components provides an additive means of producing white light having a lower color temperature with little or no color loss, rather than a subtractive means such as that provided by use of colored filters and any attendant color losses associated therewith. The above arrangement, by ensuring a constant drive current to the LEDs, significantly reduces the sensitivity of the resultant color temperature to aging, ambient temperature, etc.

Although the description above contains several specific patterns and mixtures of case sizes, shapes, etc., these should not be construed as limiting the scope of the invention but as merely providing illustrations of some of the currently preferred embodiments. For example, the LEDs may be arranged in circular or other shaped patterns. In some applications, the 3 mm and 5 mm cylindrical LEDs may be mixed with surface mount units to obtain a desired effect.

Further, although various specific circuit configurations have been shown and described above, there are numerous driving circuits which can be utilized with the present invention, the specific design of which will be evident to one of skill in the art given the detailed description herein. For example, each of the circuits described herein can be modified to operate from an AC voltage source by designing the DC power source as an AC/DC converter. Also, even though not shown in the figures, the drive circuits can be configured to be manually adjustable or adjustable with a programmable microprocessor.

Thus, although the present invention has been described in relation to particular embodiments thereof, many other variations and modifications and other uses will become apparent to those skilled in the art. It is preferred, therefore, that the present invention be limited not by the specific disclosure herein, but only by the appended claims.

What is claimed is:

1. A temperature adjustable LED arrangement comprising:

at least one white LED;

a first drive circuit operable to supply a first drive current to the at least one white LED such that a white light is output at a first intensity;

at least one colored LED arranged such that a colored light is output from the at least one colored LED and combines with the white light to produce a resultant light having a color temperature; and

a second drive circuit operable to supply a second drive current to the at least one colored LED such that the colored light is output at a second intensity, the second drive circuit being adjustable so as to adjust a level of the second drive current supplied so as to vary the color temperature of the resultant light; wherein the color temperature of the resultant light is adjustable between about 2500 to about 5000 degrees Kelvin.

2. The LED arrangement according to claim 1, wherein the first drive circuit is adjustable so as to adjust a level of the first drive current supplied to the at least one white LED so as to vary the brightness of the white light.

3. The LED arrangement according to claim 1, wherein the at least one colored LED is an amber LED.

4. The LED arrangement according to claim 1, wherein the at least one colored LED is a combination of red and yellow LEDs.

5. The LED arrangement according to claim 1, wherein the first drive circuit is a pulse width modulated drive circuit with active current limiting.

6. The LED arrangement according to claim 5, wherein the second drive circuit is a pulse width modulated drive circuit with active current limiting.

7. The LED arrangement according to claim 1, wherein the second drive circuit is a pulse width modulated drive circuit with active current limiting.

8. The LED arrangement according to claim 1, wherein the first drive circuit is a pulse width modulated drive circuit with passive current limiting.

9. The LED arrangement according to claim 5, wherein the second drive circuit is a pulse width modulated drive circuit with passive current limiting.

10. The LED arrangement according to claim 1, wherein the second drive circuit is a pulse width modulated drive circuit with passive current limiting.

11. The LED arrangement according to claim 1, wherein the at least one white LED is a discrete LED.

12. The LED arrangement according to claim 11, wherein the at least one white LED is mounted on a printed circuit board.

13. The LED arrangement according to claim 1, wherein the at least one white LED is a chip-on-board LED.

14. The LED arrangement according to claim 1, wherein the at least one white LED comprises at least two white LEDs arranged in series.

15. The LED arrangement according to claim 1, wherein the at least one colored LED is a discrete LED.

16. The LED arrangement according to claim 15, wherein the at least one colored LED is mounted on a printed circuit board.

17. The LED arrangement according to claim 1, wherein the at least one colored LED is a chip-on-board LED.

18. The LED arrangement according to claim 1, wherein the at least one colored LED comprises at least two colored LEDs arranged in series.

19. The LED arrangement according to claim 1, wherein the color temperature of the resultant light is adjustable to about 3600 degrees Kelvin.

20. A method of adjusting the color temperature of light output from an LED arrangement, the method comprising:

supplying a first drive current to at least one white LED such that a white light is output at a first intensity;

supplying a second drive current to at least one colored LED such that a colored light is output at a second intensity;

combining the white light with the colored light to produce a resultant light having a desired color temperature; and

adjusting the color temperature of the resultant light by adjusting the second intensity of the colored light;

wherein the color temperature of the resultant light is adjusted between about 2500 to about 5000 degrees Kelvin.

21. The method of adjusting the color temperature of light output from an LED arrangement according to claim 20, wherein the color temperature of the resultant light is adjusted to about 3600 degrees Kelvin.

22. A temperature adjustable LED arrangement comprising:

at least one white LED;

a first drive circuit operable to supply a first drive current to the at least one white LED such that a white light is output at a first intensity;

at least one red LED arranged to output a red light that combines with the white light;

a second drive circuit operable to supply a second drive current to the at least one red LED such that the red light is output at a second intensity;

at least one yellow LED arranged to output a yellow light that combines with the white light and the red light to produce a resultant light having a color temperature;

a third drive circuit operable to supply a third drive current to the at least one yellow LED such that the yellow light is output at a third intensity,

the second drive circuit being adjustable so as to adjust a level of the second drive current supplied to the at least one red LED and the third drive circuit being adjustable so as to adjust a level of the third drive current supplied to the at least one yellow LED so as to vary the color temperature of the resultant light; wherein the color temperature of the resultant light is adjustable between about 2500 to about 5000 degrees Kelvin.

23. The LED arrangement according to claim 22, wherein the at least one white LED is a discrete LED.

24. The LED arrangement according to claim 23, wherein the at least one white LED is mounted on a printed circuit board.

25. The LED arrangement according to claim 22, wherein the at least one white LED is a chip-on-board LED.

26. The LED arrangement according to claim 22, wherein the at least one white LED comprises at least two white LEDs arranged in series.

27. The LED arrangement according to claim 22, wherein the at least one red LED and the at least one yellow LED are discrete LEDs.

28. The LED arrangement according to claim 27, wherein the at least one red LED and the at least one yellow LED are mounted on a printed circuit board.

29. The LED arrangement according to claim 22, wherein the at least one red LED and the at least one yellow LED are chip-on-board LEDs.

30. The LED arrangement according to claim 22, wherein the at least one red LED comprises at least two red LEDs arranged in series.

31. The LED arrangement according to claim 30, wherein the at least one yellow LED comprises at least two yellow LEDs arranged in series.

32. The LED arrangement according to claim 22, wherein the first drive circuit is adjustable so as to adjust a level of the first drive current supplied to the at least one white LED so as to vary the brightness of the white light.

33. The LED arrangement according to claim 22, wherein the color temperature of the resultant light is adjustable to about 3600 degrees Kelvin.

34. A temperature adjustable LED arrangement comprising:

at least one white LED which outputs a white light;

at least one colored LED which outputs a colored light, the at least one colored LED being arranged at a distance from the at least one white LED such that the output colored light combines with the output white light to produce a resultant light having a color temperature; wherein the color temperature of the resultant light is adjustable between about 2500 to about 5000 degrees Kelvin.

35. The LED arrangement according to claim 34, wherein an intensity of the output colored light is adjustable so as to vary the color temperature of the resultant light.

36. The LED arrangement according to claim 34, wherein the at least one colored LED is a chip-on-board LED.

37. The LED arrangement according to claim 34 wherein the color temperature of the resultant light is adjustable to about 3600 degrees Kelvin.

38. The LED arrangement according to claim 35, wherein an intensity of the output white light is adjustable so as to vary the brightness of the resultant light.

39. The LED arrangement according to claim 34, wherein an intensity of the output white light is adjustable so as to vary the brightness of the output white light.

40. The LED arrangement according to claim 34, wherein the at least one colored LED is an amber LED.

41. The LED arrangement according to claim 34, wherein the at least one colored LED is a combination of red and yellow LEDs.

42. The LED arrangement according to claim 34, wherein the at least one white LED is a discrete LED.

43. The LED arrangement according to claim 42, wherein the at least one white LED is mounted on a printed circuit board.

44. The LED arrangement according to claim 34, wherein the at least one white LED is a chip-on-board LED.

45. The LED arrangement according to claim 34, wherein the at least one colored LED is a discrete LED.

46. The LED arrangement according to claim 45, wherein the at least one colored LED is mounted on a printed circuit board.

* * * * *

US006127784A

United States Patent [19]

Grossman et al.

[11] Patent Number: 6,127,784

[45] Date of Patent: Oct. 3, 2000

[54] LED DRIVING CIRCUITRY WITH VARIABLE LOAD TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED

[75] Inventors: Hyman Grossman, Lambertville; John Adinolfi, Milltown, both of N.J.

[73] Assignee: Dialight Corporation, Manasquan, N.J.

[21] Appl. No.: 09/144,097

[22] Filed: Aug. 31, 1998

[51] Int. Cl.^{7} G05F 1/00

[52] U.S. Cl. 315/159; 315/112; 315/117; 315/158; 315/307

[58] Field of Search 315/50, 112, 117, 315/118, 224, 225, 291, 307, 151, 159, 158; 363/89, 80

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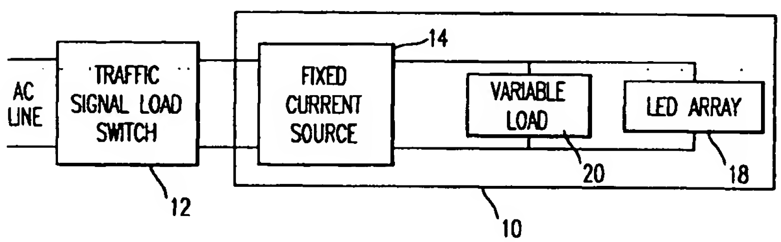
Primary Examiner—Don Wong
Assistant Examiner—Wilson Lee
Attorney, Agent, or Firm—Oblon, Spivak, McClelland, Maier & Neustadt, P.C.

[57] ABSTRACT

Circuitry for driving an LED array and a lamp including such circuitry. A fixed current source outputs a fixed current to an LED array. A variable load is provided in parallel to the LED array to also receive an output from the fixed current power supply. The variable load senses a condition affecting a luminous output of the LED array and varies an impedance based on this sensed condition. This variable load may typically include a thermistor or a photodetector. As the impedance of the variable load changes, current diverted from the LED to the variable load changes. Thereby, current supplied to the LED array, and thereby the intensity LED, can be controlled based on the impedance changing element in the variable load.

10 Claims, 1 Drawing Sheet



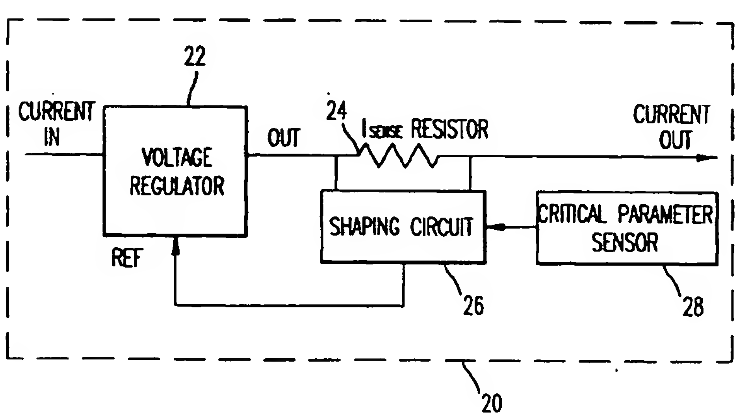


FIG. 1

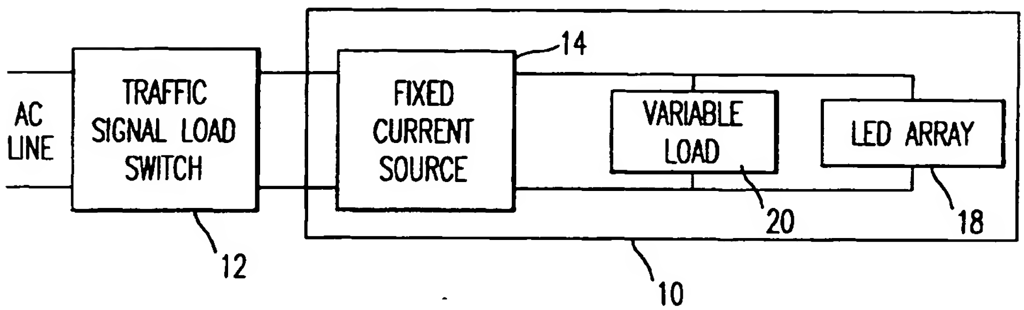
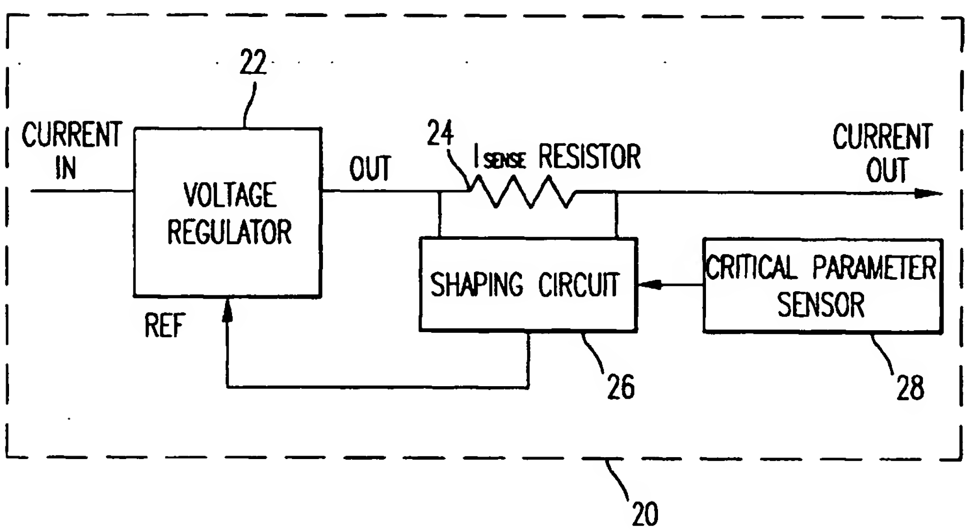

AC LINE
TRAFFIC SIGNAL LOAD SWITCH
FIXED CURRENT SOURCE
VARIABLE LOAD
LED ARRAY
14
20
18
12
10

FIG. 2


22
CURRENT IN
VOLTAGE REGULATOR
OUT
24
I SENSE RESISTOR
CURRENT OUT
SHAPING CIRCUIT
CRITICAL PARAMETER SENSOR
REF
26
28
20

LED DRIVING CIRCUITRY WITH VARIABLE LOAD TO CONTROL OUTPUT LIGHT INTENSITY OF AN LED

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to an LED lamp and a driving circuit to drive an LED array. More particularly, the present invention is directed to an LED lamp and a driving circuit which can drive an LED array with a compensation for conditions which change luminous output of the LED array. This invention can find particular application where the LED array is utilized in a device such as a traffic signal or another indicating signal.

2. Discussion of the Background

The use of LED arrays in indicating devices, such as traffic signals, is known. One drawback with using LEDs in an indicator such as a traffic signal is that luminous output of an LED degrades with both time and increasing temperature. For red LEDs degradation with respect to temperature will typically result in a loss of approximately one percent of intensity of the LED with every one degree centigrade increase in temperature. Conversely, as temperature decreases, intensity of light output by an LED increases. Moreover, LEDs gradually degrade over time, and thus become dimmer as they get older.

One known system senses a temperature at the LED or senses a light output at the LED, and utilizes the sensed temperature or sensed light output as a feedback to a power supply. Such a system is disclosed in U.S. Pat. No. 5,783,909 to Hochstein. This patent discloses (1) sensing either temperature at an LED or intensity output of an LED, (2) feeding back the sensed temperature or intensity to a power supply, and (3) then increasing or decreasing an average current output by the power supply based on any increase or decrease in temperature at the LED or any increase or decrease in the light output of the LED.

One drawback with such a system as disclosed in Hochstein is that such a system may not operate properly at low temperatures. As a specific example, a traffic signal is normally switched on and off by solid state relays. These relays may have a minimum current below which the relays cannot operate reliably. Utilizing a feedback operation such as in the device of Hochstein results in the following problems during low temperature operation of the LED array.

Because of the feedback operation in the device of Hochstein, at a low temperature a small total current is supplied to drive an LED array since the LED array is very bright at the low temperature. The total current supplied to the LED array may as a result cause the current through the load switch to fall below the minimum current required for the solid state relays to properly operate. In traffic signals it is also desirable to reduce lamp intensities at low temperatures while maintaining an input current to be compatible with a lamp controller. The device of Hochstein does not address problems of controller compatability.

OBJECTS OF THE INVENTION

Accordingly, one object of the present invention is to provide novel drive circuitry for an LED array which can overcome the drawbacks in the background art.

A further and more specific object of the present invention is to provide a novel drive circuit for an LED array in which the current supplied to the LED array can be compensated for without the use of a feedback circuit.

SUMMARY OF THE INVENTION

In one embodiment the present invention achieves these objects by forming a variable load in parallel to an LED array to be driven. This variable load has the property that the current drawn by the variable load varies based on a sensed parameter—for example, based on the sensed temperature at the LED array or the sensed intensity of light output by the LED array. This variation in current absorbed by the variable load changes the amount of current provided to the LED array, to thereby control the luminous output of the LED array.

BRIEF DESCRIPTION OF THE DRAWINGS

A more complete appreciation of the present invention and many of the attendant advantages thereof will be readily obtained as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawing, wherein:

FIG. 1 shows one implementation of an LED lamp and driving circuit according to the present invention; and

FIG. 2 shows a detailed description of a variable load of FIG. 1.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the figures, wherein like reference numerals designate identical or corresponding parts throughout the several views, a pictorial example of the LED lamp and LED driving circuitry of the present invention is disclosed.

FIG. 1 shows an LED lamp **10** of the present invention connected to a traffic signal load switch **12**, which in turn is connected to an AC power line. This disclosed embodiment in the present invention is directed to the LED lamp **10** being utilized in an LED traffic signal or similar LED indication signal. The LED lamp **10** includes a fixed current source **14** supplying power to both a variable load **20** and an LED array **18**.

The fixed current source **14** can take the form of outputting either pulses or a direct current. If the fixed current source **14** outputs pulses, these pulses will be of a fixed amplitude and frequency. If the fixed current source **14** outputs a direct current, the direct current will be constant.

The fixed current source **14** is connected to the traffic signal load switch **12**. The traffic signal load switch **12** provides power to one or more LED indication signals—i.e., to one or more LED lamps **10**. The AC voltage from the AC line is thereby delivered through the traffic signal load switch **12** to the fixed current source **14** of the LED lamp **10**.

The variable load **20** and the LED array **18** are arranged in parallel, and thereby any current absorbed by the variable load **20** is diverted from the LED array **18**. Consequently, by varying the impedance of the variable load **20**, the current passing through the LED array **18** is varied, and as a result the intensity of light output by the LED array **18** is varied.

This variable load **20** includes at least one element which senses a condition which affects the output light intensity of the LED array **18**. For example, this variable load **20** can include either a thermistor circuit or a photodetector, provided that the thermistor or photodetector is configured to provide a variable impedance load. In one embodiment, this variable load **20** includes a thermistor circuit which has a variable impedance based on temperature. As a temperature increases, the resistance of the thermistor decreases, and this

results in an increase in the impedance of the variable load 20, as discussed in further detail below. As a result, more current is diverted to the LED array 18. Thus, as the temperature at LED array 18 increases, the current supplied to the LED array 18 increases to maintain the luminous intensity of the LED array 18. A similar operation can be affected if the variable load 20 includes a photodetector as a variable impedance element which monitors light output by the LED array 18.

The above-identified operations can be summarized as follows. As temperature at LED array 18 increases or light output by LED array 18 decreases, the impedance of the variable load 20 increases. Thereby, more current from the fixed current source 14 is diverted to the LED array 18 so that the current passing through the LED array 18 increases, and as a result the illuminance of the LED array 18 increases. Thereby, any loss of illumination in the LED array 18 which results from an increase in temperature is compensated for. When a photodiode is used in the critical parameter sensor 28, any loss of intensity due to aging of the LED array 18 is compensated for as well.

FIG. 2 shows a detailed explanation of the structure of the variable load 20.

As shown in FIG. 2, the variable load 20 includes a voltage regulator 22. The voltage regulator 22 may typically be a 3-terminal voltage regulator—for example model number LM 317 manufactured by National Semiconductor among others, or an equivalent voltage regulator. An output from the fixed current source 14 is supplied to the voltage regulator 22 as the "current in", and it is also supplied to the LED array 18 as shown in FIG. 1. The variable load 20 also includes a sense resistor 24 at an output of the voltage regulator 22. Formed across the sense resistor 24 is a shaping circuit 26. A critical parameter sensor 28 provides an input to the shaping circuit 26. The critical parameter sensor 28 can be a thermistor or a photodetector with variable impedance as discussed above. The output of the shaping circuit 26 is then fed back to the voltage regulator 22.

The elements forming the shaping circuit 26 are used to model characteristics of the critical parameter sensor 28 as discussed further below. The voltage regulator 22 is configured in this embodiment to form a linear current regulator. It is well known that a linear current regulator can be made from a commonly available 3-terminal voltage regulator 22 such as noted above. Such a voltage regulator forms a linear current regulator by placing the low value current sense resistor 24 in series with the output of the voltage regulator 22 and feeding back a voltage developed across the sense resistor 24 to a reference terminal REF of the voltage regulator 22. In the embodiment shown in FIG. 2 the shaping circuit 26 is used to moderate this feedback. The shaping circuit 26 is formed of active and passive circuitry as necessary to vary the signal presented to the REF terminal of the voltage regulator 22. As the voltage generated or impedance of the critical parameter sensor 28 changes, the reference voltage applied to the REF terminal of the voltage regulator 22 will vary.

The actual active and passive components forming shaping circuit 26 will vary based on the other components in LED lamp 10 and desired characteristics for LED lamp 10. However, the shaping circuit 26 should perform certain functions. First, the shaping circuit 26 should be constructed to compensate for the non-linear response of the LED array 18 to temperature and any non-linear properties of a thermistor or photodetector as the critical parameter sensor 28.

As noted above, an LED may have a response to temperature of losing approximately 1% of light output per degree centigrade, which is a non-linear response, and a thermistor has a similar non-linear response. The shaping circuit 26 should select the active and passive components therein to address this non-linear quality of the LED array 18 and the critical parameter sensor 28.

Further, in the context of temperature compensation the shaping circuit 26 is constructed to provide a low stop to ensure that the variable load 20 always absorbs a certain current to ensure proper operation of the LED array 18. As noted above, if the current supplied to an LED falls below a certain level, the performance of the LED becomes unpredictable. This is a drawback in the background art which utilizes a feedback such that at low temperatures the current provided to an LED can drop to such a low level as to cause erratic illumination of the LED. Further, at low temperatures a current generated may be too low to switch the solid state on and off relays controlling a traffic signal. For this reason, the shaping circuit 26 should include a resistance in parallel with the critical parameter sensor 28 so that the reference voltage provided to the REF terminal of the voltage regulator 22 does not fall below a predetermined level. This ensures that the impedance of the variable load 20 does not drop too low and that the variable load 20 does not absorb too great a current at this low stop value.

In the circuit of FIG. 2, in the example that the critical parameter sensor 28 includes a thermistor, the operation is as follows. At a low temperature, the impedance of the thermistor of the critical parameter sensor 28 will be very high. However, as noted above the shaping circuit 26 includes a resistance in parallel with the thermistor of the critical parameter sensor 28 such that even if the critical parameter sensor 28 has an extremely high impedance, current still flows through the shaping circuit 26 to the REF terminal of the voltage regulator 22. This ensures that the voltage input to the reference terminal REF of the voltage regulator 22 still maintains a minimum value, so that the "current out" is not too high. This results in the variable load 20 maintaining an overall minimum impedance—i.e., the overall impedance of the variable circuit 20 does not fall below a predetermined level. This results in a minimum current always passing through the LED array 18. If the shaping circuit 26 is not appropriately configured with a low stop as discussed above, then the impedance of the variable load 20 may drop to too low a level. In that case, too much current will be diverted from the LED array 18. As noted above, if the LED array 18 does not receive an adequate driving current, illumination of the LED array becomes unpredictable.

Conversely, under very high temperature conditions the impedance of the thermistor in the critical parameter sensor 28 becomes very low. The voltage then input to the reference terminal REF of the voltage regulator 22 becomes very high, and as a result the "current out" is restricted. Thus, the variable load 20 in this high temperature operation takes on a very high impedance. This ensures that more current is diverted from the fixed current source 14 to the LED array 18 to increase the current passing through the LED array 18, to compensate for any temperature induced losses in intensity of light output by the LED array 18. No high stop structure is required in the present invention since even if the variable load 20 has an infinite resistance, this will only result in the LED array 18 receiving all of the current output from the fixed current source 14. The fixed current source 14 then should be selected to output a fixed current which if totally applied to the LED array 18 does not damage the LED array 18.

The above discussion has focused on an example in which the critical parameter sensor 28 is a thermistor. Similar operations as noted above also are effectuated if the critical parameter sensor 28 is a photosensor which has a variable impedance based on a detected light output.

If the critical parameter sensor 28 is a thermistor, this critical parameter sensor 28 should be placed closed enough to the LED array 18 to determine the temperature at the LED array 18. If the critical parameter sensor 28 is a photodetector, this photodetector should be placed near the LED array 18 to receive an indication of light output by the LED array 18. Further, if the critical parameter sensor 28 is a photodetector, the photodetector should be appropriately shielded from ambient light so that the photodetector only detects the intensity of light output by the LED array 18.

Also, the present invention can be applied to any driving circuit for any number of LEDs and arrays of LED, and it is not limited to driving one LED array.

Obviously, numerous modifications and variations of the present invention are possible in light of the above teachings. It is therefore to be understood that within the scope of the appended claims, the present invention may be practiced otherwise than as specifically described herein.

We claim:

1. Apparatus for indicating signals comprising:

(a) an LED array;

(b) a fixed current source which, in use, outputs a fixed current; and

(c) a variable load electrically connected in parallel to the LED array, said variable load including a parameter sensor which has a variable impedance based on a condition affecting luminous output of the LED array, said LED array and said variable load both receiving, in parallel electrically, said fixed current output of said fixed current source.

2. The driving circuit according to claim 1, wherein:

(a) said the parameter sensor is a thermistor, and

(b) the condition is the temperature at the LED array.

3. The driving circuit according to claim 1, wherein:

(a) said parameter sensor is a photosensor, and

(b) the condition is an intensity of light output of the LED array.

4. The driving circuit according to claim 1, wherein said variable load further includes a shaping circuit having a resistance in parallel to said parameter sensor.

5. The driving circuit according to claim 4, wherein said variable load further includes a voltage regulator which, in use, receives the fixed current from said fixed current source and receives an output of said shaping circuit as a feedback reference voltage.

6. Apparatus for indicating signals comprising:

(a) an LED array;

(b) means for supplying a fixed current; and

(c) means for varying an impedance, including a parameter sensor, in parallel electrically to the LED array based on a condition affecting luminous output of the LED array, said LED array and said means for varying an impedance both receiving, in parallel electrically, said fixed current output of said means for supplying a fixed current.

7. The driving circuit according to claim 6, wherein:

(a) said means for varying an impedance includes a thermistor, and

(b) the condition is the temperature at the LED array.

8. The driving circuit according to claim 6, wherein:

(a) said means for varying an impedance includes a photosensor, and

(b) said condition is the intensity of light output of the LED array.

9. The driving circuit according to claim 6, wherein said means for varying an impedance includes a shaping circuit.

10. The driving circuit according to claim 9, wherein said means for varying an impedance further includes a voltage regulator which, in use, receives the fixed current from the means for supplying a fixed current and receives an output of said shaping circuit as a feedback reference voltage.

* * * * *